Neurovascular MRA Techniques, Pitfalls, and Problem Solving

Ronald L. Wolf, M.D., Ph.D.
Assistant Professor of Radiology, University of Pennsylvania Medical Center

Technique

MRA and increasingly CTA are widely used for evaluation of intracranial and extracranial cerebrovascular disease. There are 3 basic MRA techniques available for routine imaging, all of which are “bright blood” techniques (lumen is bright relative to background):

1. Time of flight (TOF) MRA: 2D or 3D
2. Phase contrast (PC) MRA: 2D or 3D
3. Contrast-enhanced MRA (CEMRA): 3D

TOF MRA relies on a fast, limited flip angle gradient echo sequence, with contrast between vessel and background generated from inflow of fresh unsaturated spins between pulses while the background becomes saturated. PC methods rely on motion-induced phase shifts as well as saturation of the background to generate contrast. This method can also be used to measure velocity and/or volumetric flow rates in vessels, and this can include the direction or vector of flow. Contrast is generated in CEMRA methods by imaging the vessel as a T1-shortening agent like a gadolinium-based contrast agent moves through it, making this method less sensitive to flow-related artifacts. These sequences are fast and have a very short TE, both of which help to minimize flow-related artifacts as well. There are advantages and disadvantages to each; for example, for the unenhanced techniques, 2D TOF and PC methods are more sensitive to slow flow, while 3D TOF MRA is better for fast and/or disordered flow[1-3].

A fourth category of bright-blood MRA methods consists of modifications to 3D CEMRA, incorporating techniques (or combinations of techniques) such as keyhole imaging, parallel imaging, and undersampled back projection[4]. Also, in addition to the bright blood techniques, there is also a role for “black blood” techniques (lumen dark compared to vessel wall or background), which can be very useful for evaluating the wall of the artery (e.g., carotid plaque or intramural thrombus in the setting of acute dissection).

With the proliferation of newer multidetector scanners, CT angiography or CTA is also becoming routine for noninvasive vascular imaging. Issues of ionizing radiation and iodinated contrast of course remain, but risk is still low and the technique is robust. It is often better tolerated by patients, more accessible, and easier to implement in some patients, particularly those who are unstable.

An extensive discussion of the technical aspects is beyond the scope of this lecture but can be found in many excellent reference texts and articles, a few of which are listed below (but please note that the list is by no means comprehensive). The emphasis here will be on clinical applications and problem solving with MRA, incorporating references to CTA when appropriate. The table (adapted from [5]) summarizes some of the major problems (and solutions) encountered in clinical neurovascular imaging.

Clinical Applications

Intracranial Circulation

3D TOF MRA and CTA are the workhorses for routine evaluation of the circle of Willis. Phase contrast MRA techniques are not very commonly used, except in the setting of venous thrombosis or if directional information or velocities are desired. The primary indications for intracranial MRA (or MRV) are aneurysm, intracranial stenotic-occlusive disease, and venous thrombosis. CTV can be used for venous thrombosis as well. The role for noninvasive imaging in evaluation of vasculitis intracranially is unclear. If you see it, you can question it, but a negative study is not adequate in this setting. Routine imaging of AVM or AVF is not typically done, as these cases are still more effectively evaluated with conventional angiography[6, 7]. However, it is still important to be able to recognize them. There are situations where MRA can help guide the angiographer (e.g. dural AVF, although it is more helpful in the spine). Temporal resolution is however improving for realistic implementation of MR DSA[8-12].

One of the most common applications is in the evaluation of intracranial aneurysms. MRA is not the study of choice in a patient with acute subarachnoid hemorrhage, but there is definitely a role for following known unruptured aneurysms and screening high-risk populations such as patients with autosomal dominant polycystic kidney disease. CTA has a prominent role for preoperative evaluation of intracranial aneurysms, either as an adjunct to conventional angiography or in some cases replacing it. For example, CTA can provide essential diagnostic and surgical planning information in the setting of catastrophic SAH. In some centers, CTA alone is used for routine SAH workup[13, 14]. Detection of small aneurysms (<3mm) is less reliable with MRA or CTA[15]. Giant aneurysms or previously coiled aneurysms merit special attention. Evaluation of giant aneurysms should include PC MRA or CEMRA, as slow and/or disordered flow can lead to dramatic signal loss with a conventional TOF approach. CTA is also very useful in this setting. Similarly, CEMRA can often provide excellent delineation of the region of the neck of a previously coiled aneurysm, and is a reasonable alternative if there is insufficient motivation to pursue conventional angiography. Even standard 3D TOF MRA can often adequately demonstrate aneurysm residuals in previously coiled aneurysms[16-18]. CTA on the other hand is not very good in evaluating previously coiled aneurysm necks.

For stenotic-occlusive disease, intracranial MRA is usually reliable for depicted normal or occluded vessels, although very slow flow can easily mimic an occlusion (CTA can be helpful here)[19, 20]. Assessing degree of stenosis in between these extremes is more difficult. Vasculopathies like vasculitis, moyamoya disease and sickle cell disease can be evaluated to an extent, but at least part of the advantage to using MR techniques in this setting is the superior evaluation of the brain itself with imaging performed at the same time as the vascular workup. Vasospasm can be evaluated with CTA in SAH patients, often coupled with perfusion CT.

There is certainly a role for MR or sometimes CT evaluation of the venous system. Some advocate routine PC MRV, avoiding the possibility of T1-bright thrombus mimicking flow, which can occur with TOF techniques. Contrast-enhanced MRV techniques are also available, and can provide exquisite venograms[21, 22]. CTV is employed less often, but also can provide very detailed venograms.

Extracranial Circulation

The vast majority of cases in which noninvasive imaging is applied in this setting will be for evaluation of atherosclerotic stenotic-occlusive disease, carotid or vertebral artery dissection, and traumatic injury. We are most commonly asked to evaluate degree of carotid stenosis, although vessel wall irregularity or ulceration is also important, as are the presence of fibrous cap thinning, hemorrhage in the plaque, or necrotic core if we can accurately image the latter. The role for carotid endarterectomy has been established by multiple trials, including the NASCET trial which initially showed a benefit for 70-99% stenosis. There is some evidence that more moderate reduction in the risk of stroke for 50-69% stenoses might be achieved, but this is still under debate[23]. There is a large body of literature dedicated to comparison of noninvasive imaging (MRA, CTA, and/or DUS) with DSA, in attempts to replace conventional angiography for preoperative evaluation[24-27]. In reality, 3D techniques should be more likely to give a more accurate representation of minimal diameter since there are essentially infinite projections as compared to the limited number of projections obtained with conventional DSA. Comparisons of noninvasive methods may be more realistic with rotational DSA[28].

In general, MRA tends to overestimate stenoses and CTA tends to underestimate, but there is fairly good agreement. There is evidence that a combination of noninvasive tests can reduce error[27] and many physicians will accept concordant MRA and DUS depiction of a surgical lesion as sufficient for preop evaluation, with DSA reserved for discordant results, restenosis after prior endarterectomy, etc. MRA and CTA usually do not miss occlusions, but there are definitely false positives and negatives. MRA can provide information on flow direction and velocity if desired. For example, it is easier to document subclavian steal with MRA than CTA, which does not provide these parameters. Stents are better evaluated with CTA.

Arterial dissections can be extrinsic in etiology (as in trauma) or can be related to intrinsic vessel wall pathology. Dissections recurring in the same vessel or occurring in multiple vessels should prompt a search for intrinsic pathologies like FMD. Spontaneous extracranial dissections usually occur in the proximal cervical internal carotid artery just after the bifurcation, rarely in common carotid artery. They usually do not extend into the petrous carotid. These often do well, as opposed to intracranial dissections which often have a poor prognosis. Hematoma often forms in the wall of the vessel, sometimes with intimal flap, although intimal disruption is not always present. Imaging findings include tapered narrowing of the lumen, irregularity and/or caliber changes, intramural hematoma, and pseudoaneurysms. Detection of intramural hematoma using black blood MRI is useful for carotid arteries, but less reliable for vertebral arteries. The source images for TOF MRA can also be used to visualize wall abnormalities such as intramural hematoma in many cases[29, 30].

FMD or arteritides like Takayasu arteritis are not common, but still often seen. For these entities, the first step is to evaluate the lumen, but it is important to remember that there is also information in the wall of the vessel itself[31, 32]. For example, Takayasu arteritis may or may not show much narrowing of the lumen, but does show prominent vessel wall thickening proximally. As mentioned above, black blood techniques are perhaps better suited for evaluation of the vessel wall, but even the source images from a TOF MRA can clearly show mural thrombus in a dissection.

While CTA is excellent for penetrating injuries, there is little role for MRA in this setting. Evaluation of blunt traumatic injury is increasingly requested using MRA. MRA should be better at detecting subtle intimal injuries in the setting of blunt trauma to the neck (e.g., seat belt injuries). The same can be said for vertebral artery evaluation with cervical spine injuries. In practice, however, both CTA and MRA are used for blunt injury evaluation[33-36].

Spinal Cord

Spinal MRA can be performed for preoperative localization of the artery of Adamkieweicz. The site of AV fistulae may also be identified and thus spinal angiography procedures shortened. CE MRA methodology is usually applied, with the usual trade-offs between spatial and temporal resolution[37-40].

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Summary of problems in MRA and potential solutions. (IVPD, intravoxel phase dispersion; PC, phase contrast; TOF, time-of-flight; CE MRA, contrast-enhanced MRA; TRICKS, *T*ime *R*esolved *I*maging of *C*ontrast *K*inetic*S*; PR, projection-reconstruction)

Problem	Technique	Effect on MRA	Location	Solution
Complex flow	PC, TOF	IVPD, Signal loss	Near stenosis Carotid bulb Giant aneurysm Loops and curves	Decrease TE Flow compensation 3D TOF instead of 2D TOF Smaller voxels Larger flip angle
Slow flow	TOF > PC	Saturation, Signal loss	Distal to stenosis Vessel in plane Aneurysm Dolichoectasia	Thin sections or MOTSA Lower or ramped flip angle Perpendicular section Gd-based contrast Lower velocity encoding (PC)
T1-shortening	TOF > CE MRA	Bright signal interferes with vessel contrast	T1-bright thrombus, adjacent fat	PC MRA Optimized CE MRA Fat saturation Subtraction
Susceptibility	TOF, PC > CE MRA	Signal loss adjacent to blood products (some ages), metal	Hemorrhagic lesions, surgical clip or stents	Shorten TE Gd-based contrast
Aliasing	PC	Misinterpretation, signal loss	Any vessel	Correct velocity encoding
Ghosting, Misregistration, Motion	TOF, PC	Signal loss, indistinct vessels, obscured perivascular anatomy	Any vessel	Motion correction Rapid imaging (short-TR/TE, partial Fourier, undersampling, parallel imaging)
Timing errors	CE MRA	"Tram-tracks", poor artery contrast, venous contamination, signal loss near bolus	Any vessel	Correct timing
Spatial vs. Temporal Resolution	All	Inadequate evaluation of dynamic lesion	AVM, AVF	MR DSA methodology (TRICKS, undersampled PR, parallel imaging, etc.)